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THE EFFECT OF EXPOSURE TIME, INDIVIDUAL VARIABILITY, AND PRACTICE ON THE PRECISION OF VERNIER ADJUSTMENTS

H. W. LIEBOWITZ
NOEL KAESTNER

UNIVERSITY OF WISCONSIN

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WRIGHT AIR DEVELOPMENT CENTER

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H. W. Liebowitz
Noel Kaestner

University of Wisconsin

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FOREWORD

This report represents a study designed to investigate the effect of practice, exposure time, and individual variability on the precision with which an individual can align two straight edges.

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ABSTRACT

The effect of practice, individual variability, and duration of exposure on the precision with which a subject can align two straight edges was investigated. For untrained subjects, precision becomes poorer with decrease in either duration of exposure or luminance. Some subjects improved their performance with practice but the average acuity values for 32 subjects showed no significant changes. Individual differences with respect to practice and to the variables of luminance and exposure time were unusually large.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

INTRODUCTION

In the first paper of this series of experiments, the relationship between several stimulus factors and the precision with which a subject can align two straight edges was reported (1). The present report represents an extension of this study to include the influence of exposure time and individual variability on such vernier adjustments. Because of the high accuracy of vernier acuity, the possibility of utilizing vernier configurations to present information on a display is suggested. In this respect it is of interest to know how vernier discriminations are affected by poor viewing conditions. In particular, information concerning the effect of short durations of exposure would be of value since previous investigators have reported that unlike other measures of visual resolution, a deterioration in vernier acuity results from brief exposures which apparently can not be improved by increased luminance (2). It is also important to know how the precision of vernier adjustments varies in a population of subjects, most published reports having been based on data from a few individuals. The use of untrained subjects would also permit analysis of practice effects and would be helpful in predicting performance on tasks requiring vernier discriminations.

APPARATUS AND PROCEDURE

The apparatus employed in the original experiments was modified by the addition of a rectangular border to the test field to aid in orienting the eye, and an artificial pupil 2.5 mm in diameter. Provision was also made for presenting the vernier test objects for brief durations of exposure as well as continuously.

The stimulus bars as they appear to the subjects are schematically diagrammed in Fig. 1. The bars, viewed in transmitted light, are white and each subtends 7.16 minutes of arc in width and 35.8 minutes of arc in length at the viewing distance of 10 feet. The inner boundaries of the fixation border subtend 28.7 by 100.3 minutes of arc and the width of the border is 28.7 minutes of arc. Continuous illumination of the test object bars is provided by a 200 watt projection bulb drawing 1.6 amperes A. C. Exposure of the bars for .0002 seconds is accomplished by discharging 100 microfarads at 450 volts, D. C., through a F. A. 104 Sprague electronic flash-tube. The fixation border is illuminated by a fluorescent light.

The subjects are introduced to the apparatus by first showing them the stimulus field with the bars illuminated continuously and not in alignment (Fig. 1A). They are told that their task is to adjust the upper limb of the test object, by means of a knob, so that the edges of the bars coincide (Fig. 1B). In order to be certain that the subjects understand, they are allowed to make one adjustment before beginning the experiment. For experimental sessions involving the short duration of exposure, the test object is illuminated every five seconds and the subject attempts to align the test object limbs between

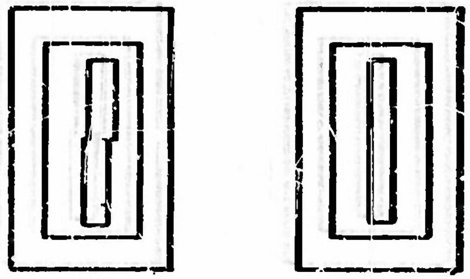

Fig. 1. Schematic diagram of the subjects' view of the test field.
A- at beginning of adjustment;
B- after adjustment has been made by subject.

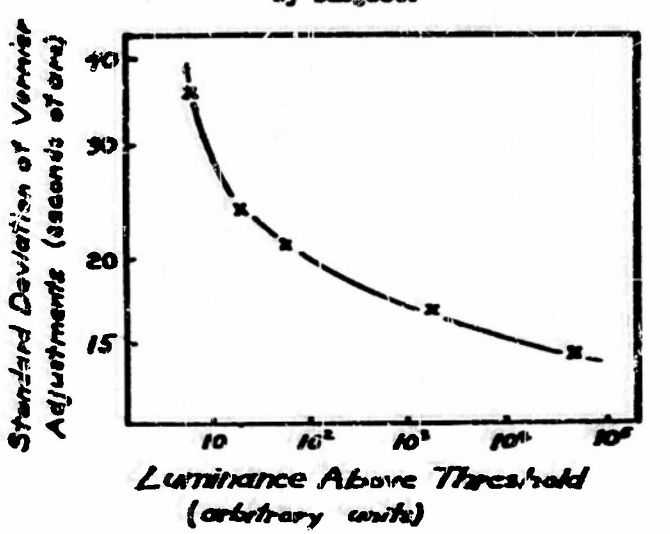

Fig. 2. Mean of standard deviations of vernier adjustments as a function of luminance above absolute threshold (0.01 millilambert). Data are for three untrained subjects. Duration of exposure was 0.0002 seconds.

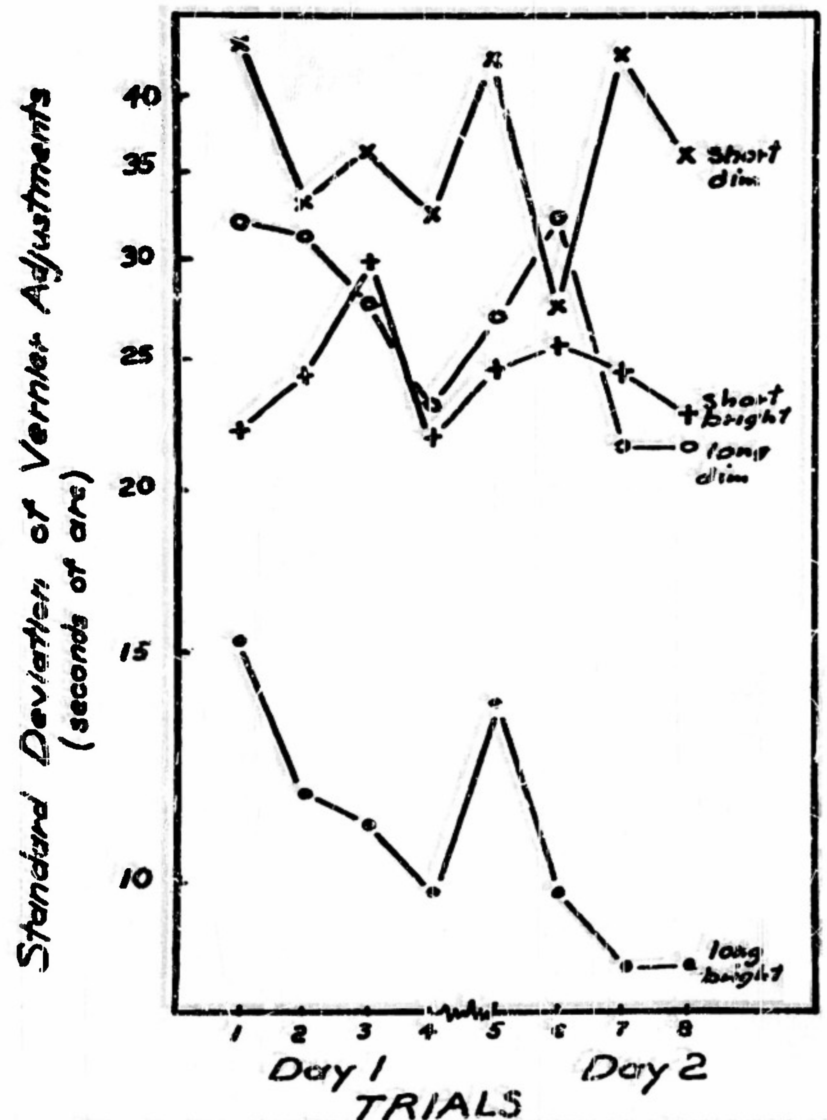

Fig. 3. Mean standard deviation of vernier adjustments as a function of practice. Each trial is based on ten vernier adjustments. Eight subjects served in each group. See text for explanation of stimulus conditions.

successive exposures. Between flashes, only, the fixation border is visible. After a maximum of 10 flashes, the position of the upper limb is recorded from a micrometer, the upper limb is offset (randomly to the right and to the left), and the procedure is repeated. Movement of the control knob (one inch diameter) through one revolution displaced the upper limb of the test object by 33 seconds of arc.

Calibration of the luminance produced by the flash tube could not be done in a conventional manner because of the extremely short duration. Instead, the absolute threshold for the test object was determined for both the flash and for continuous exposure with the incandescent source. Luminance specification for the short duration is expressed relative to the absolute threshold for the flash. The corresponding value for the incandescent lamp is .01 millilambert. The maximum luminance produced by the continuous source was 425 millilamberts, the fixation border was always one half this amount.

PRELIMINARY EXPERIMENT

Three untrained subjects, male undergraduates who were paid for their services, were required to make ten vernier adjustments at the short duration of exposure for luminance levels of 0.7, 1.2, 1.7, 3.2, and 4.7 $\log_{10}$ units above absolute threshold. Ten minutes dark adaptation preceded each experimental session after which the luminance levels were tested in ascending order. This procedure was repeated for four consecutive days. As an inverse measure of vernier acuity, the standard deviation in seconds of arc of the ten coincidence adjustment was computed. The individual results are presented in Table I and the average curve in Fig. 2.

The average curve exhibits the same relationship as previously reported for unlimited duration of exposure (1) and by Baker for an exposure duration of .02 seconds (2). The variability of coincidence settings decreases with increase in luminance level, rapidly at first and then more slowly as the curve approaches a limiting value. The individual data reveal that there is improvement in performance from session one to session two for all subjects at all levels of luminance except the lowest, at which one subject showed no decrease in variability. There are no consistent trends in improvement for the remaining two sessions. Of interest also are the values of the best scores for the subjects Bu and Bt which are as good or better than the best acuities previously reported for unlimited duration of exposure with the same apparatus (1).

MAIN EXPERIMENT

In the light of the preliminary results, it was decided to investigate the effect of practice while comparing performance at the short and unlimited duration of exposure and for only two luminance levels. A total of 32 male undergraduates serving for pay were each assigned randomly to one of four stimulus conditions of long-dim, long-bright, short-dim, and short-bright. At the long exposure, the luminance value of the test object was 425 millilamberts for the bright condition and .085 millilambert for the dim group, the test

TABLE I

Standard Deviation of Vernier Adjustments in Seconds of Arc as a Function of Luminance for Four Experimental Sessions. Duration of Exposure Was .002 Second.

Subject	Session	Luminance (Log_{10} Units Above Threshold)				
		0.7	1.2	1.7	3.2	4.7
	1	45.6	25.2	16.8	16.8	21.6
Bt	2	30.6	22.2	16.2	12.6	18.0
	3	42.0	16.8	15.6	23.4	14.4
	4	42.0	27.0	18.0	9.6	9.6
	1	57.6	27.0	35.4	16.8	15.0
Bu	2	42.0	15.6	16.2	10.2	9.0
	3	26.4	15.0	14.4	16.8	4.7
	4	32.4	23.4	13.8	16.2	9.0
	1	38.4	46.8	45.6	26.4	15.6
Pk	2	40.2	25.8	15.0	10.2	11.4
	3	19.2	29.4	25.2	18.0	24.6
	4	12.6	13.6	21.6	18.3	21.6

objects being visible continuously. For the short exposure, the same procedure was followed as in the preliminary experiment and the luminance levels for the two groups were in the same ratio to the absolute threshold as for the continuous exposure conditions. Ten minutes dark adaptation preceeded each experimental session for the dim conditions and five minutes for the bright luminance levels.

All subjects, none of whom were used in previous experiments with the apparatus, made 80 vernier adjustments divided into eight trials of ten adjustments each. Trials one through four were run on the first experimental day and the remaining trials on the following day. The standard deviations in seconds of arc are tabulated in Table II, and the means as a function of trials are plotted in Fig. 3.

Statistical comparison of trial one with trial eight, summarized in Table III, reveals that the improvement in performance demonstrated by three of the four stimulus groups is insignificant. Comparison of trial one with trial two, Table IV, also shows that all group changes are not statistically reliable. An overall analysis of variance, summarized in Table V, demonstrates the significance of both luminance level and duration beyond the .01 level of confidence.

TABLE II

Standard Deviation of Vernier Adjustments in Seconds of Arc as a Function of Practice for Four Stimulus Conditions. Each Trial Is Based on Ten Vernier Adjustments. Trials One to Four Were Run on the First Experimental Day, Trials Five to Eight on the Following Day.

Trials (Short-Dim)

Subject								
He	44.8	47.2	61.0	52.8	67.3	89.4	77.4	71.9
Br	53.3	26.2	23.1	34.2	31.7	15.2	30.1	29.4
Wt	40.0	30.6	44.0	31.5	48.7	25.0	25.7	25.0
Me	42.2	17.8	14.1	21.1	25.8	11.9	41.6	23.8
Ta.	52.8	37.9	30.3	21.8	21.7	33.6	25.0	23.8
Dr	48.2	32.2	54.9	36.6	81.2	45.4	32.3	44.9
So	40.0	34.9	27.4	31.1	36.1	28.5	35.1	27.5
Be	32.3	38.3	35.7	34.1	31.2	51.9	78.7	42.1

Trials (Long-Dim)

Pe	14.7	13.3	10.5	11.8	25.0	8.2	14.6	11.0
Kb	11.6	24.5	24.5	39.3	7.5	19.3	6.9	14.5
Co	43.2	49.7	49.9	18.3	37.6	46.4	40.8	45.0
An	56.9	41.6	33.4	35.1	39.6	38.5	27.4	20.1
Pr	27.7	26.2	15.4	13.7	33.7	18.5	19.4	23.2
Ba	58.0	48.3	30.0	22.4	38.6	40.5	25.0	19.1
Ki	13.3	20.7	26.4	23.6	14.7	57.0	20.1	15.6
Pa	33.4	27.2	33.4	21.3	19.8	30.9	16.8	21.7

Trials (Short-Bright)

Ku	8.4	21.4	18.3	16.8	17.8	20.9	14.2	13.5
My	14.3	11.9	15.8	13.3	20.1	19.8	17.8	14.7
Es	38.1	34.1	41.5	31.4	16.4	18.3	23.1	13.7
Mc	36.9	28.7	49.1	45.6	37.9	47.2	44.2	46.0
Pl	19.0	22.2	18.5	18.5	15.0	9.6	7.8	7.3
Dw	13.5	15.6	14.0	9.2	19.4	18.7	13.6	13.4
Da	23.0	24.8	32.4	26.0	52.0	50.7	55.3	47.2
Gr	22.9	35.2	48.5	16.3	20.0	20.7	19.0	24.7

Trials (Long-Bright)

Sp	18.9	12.8	9.7	11.8	13.5	10.9	7.3	9.2
Ad	9.7	12.3	10.2	8.2	7.6	9.6	8.4	8.4
Go	6.9	11.0	4.8	6.1	5.2	5.6	11.4	5.4
Si	10.4	11.5	11.6	8.7	12.5	9.8	5.5	3.9
La	17.0	17.4	17.5	18.5	11.7	9.6	8.1	14.8
El	13.2	6.4	9.6	6.5	28.1	10.9	10.8	9.5
Re	10.7	9.0	11.1	8.3	14.1	6.5	8.6	9.2
Yo	35.2	12.2	14.1	9.6	15.7	15.5	7.7	6.6

TABLE III

Improvement Measures from Trials One to Eight.

Exposure Time	Luminance Level: Dim	Luminance Level: Bright	Row Marginals
Short	$\Sigma x = 65.63$ $\Sigma x^2 = 2,995.52$	$\Sigma x = -4.32$ $\Sigma x^2 = 1,431.57$	61.31
Long	$\Sigma x = 89.32$ $\Sigma x^2 = 3,080.28$	$\Sigma x = 53.82$ $\Sigma x^2 = 966.64$	143.14
Column Marginals	154.95	49.50	204.45

Summary Table (for above data)

Source	Sum of Squares	df	Mean Square	F
Exposure	209.26	1	209.26	----
Luminance level	347.47	1	347.47	1.48
Interaction	37.10	1	37.10	----
Error	6,573.93	28	234.78	
Total	7,167.77			

TABLE IV

Improvement Measures from Trials One to Two.

Exposure Time	Luminance Level: Dim	Luminance Level: Bright	Row Marginals
Short	$\Sigma x = 88.55$ $\Sigma x^2 = 1,964.64$	$\Sigma x = -17.72$ $\Sigma x^2 = 427.32$	70.83
Long	$\Sigma x = 15.36$ $\Sigma x^2 = 956.85$	$\Sigma x = 29.26$ $\Sigma x^2 = 641.40$	44.62
Column Marginals	103.91	11.54	115.45

Summary Table (for above data)

Source	Sum of Squares	df	Mean Square	F
Exposure	21.47	1	21.47	----
Luminance level	266.63	1	266.63	2.66
Interaction	451.28	1	451.28	4.50*
Error	2,834.31	28	101.23	
Total	3,573.69	29		

*Significant at .05 level of significance.

TABLE V

Acuity Measures**as a Function of Intensity and Duration.

Exposure Time	Luminance Level		Row Marginals
	Dim	Bright	
Short	19.7448 48.8519,9604	18.0371 40.9165,4565	37.7819
Long	18.4901 42.9136,6125	15.4565 29.9438,1673	33.9466
Column Marginals	38.2349	33.4936	71.7285

Summary Table (for above data)

Source	Sum of Squares	df	Mean Square	F
Luminance Level	.4596726	1	.4596726	20.292**
Exposure	.7024976	1	.7024976	31.011**
Interaction	.0549373	1	.0549373	2.425
Replication	.6343487	28	.0226531	----
Total	1.8514562	31	---------	----

**Significant beyond the .01 level of significance.

Inspection of the individual data shows that six of the eight subjects in the short-dim group improved from trial one to trial two, while the other two subjects performed progressively poorer with practice. For the other three stimulus groups, some subjects show improvement, some remain the same, while others become less precise as a function of practice. Individual differences are large, some of the scores in the stimulus group which on the average gives the best performance (long-bright) were poorer than the best scores from the group giving the poorest performance (short-dim). Within a given group, difference in scores as large as seven to one are found.

DISCUSSION

The improvement in the precision of vernier adjustments which occurs for some subjects is seen, upon analysis of a larger group, not to hold for all individuals. The improvement which does occur is primarily during the first 20 adjustments for the short-duration, low luminance level, altnough some subjects for all stimulus conditions become more precise with practice. The discrepancy among individuals is marked, some showing improvement while others remain the same or perform less precisely with practice. Individual

differences are also unusually large. These results suggest that further analysis of vernier performance may lead to the identification of factors responsible for these differences. In particular, it would seem important to analyze the effects of cues signaling the onset of the short duration flash, instruction in "bracketing" procedure, information concerning performance, rate of presentation of flashes, adaptation level of the eye, and motivational factors as they influence both acquisition of skill and the relative performance under short and long durations of exposure.

The superiority of the long over the short duration of exposure for comparable levels of luminance and the improvement resulting from increased luminance level are in agreement with the results of previous investigators (2, 3). The acuity function for both exposure conditions decreases in variability with luminance, rapidly at first and then more slowly as it approaches a limiting value of acuity at the higher luminance values. The effect of decreasing the duration of exposure is to shift this entire function to high values of variability.

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